

Impact of the relatively light fourth family neutrino on the Higgs boson search

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The existence of a fourth fermion generation has mostly been considered as a source of enhanced Higgs signals with respect to the 3 family Standard Model predictions. However, a fourth Standard Model family neutrino could cause the opposite situation. It is shown that relatively light fourth family neutrino ($2m_{\nu_4} < m_H$) could drastically change the interpretation of the search results for the Higgs boson, especially if $m_H < 170$ GeV.

Discovery of the Higgs boson will complete confirmation of the Standard Model (SM) basics. It is well known that the fourth SM family fermions (for the remainder of this text, SM with three and four families will be denoted as SM3 and SM4, respectively) have strong influence on the Higgs boson properties [1–11]. Especially, cross-section of the Higgs boson production via gluon fusion at hadron colliders is essentially enhanced from about nine times at the low Higgs boson mass values, to about four times at the high values of the Higgs boson mass. If mass relations forbid decays of the Higgs boson into fourth family fermions, this enhancement moves to $gg \rightarrow H \rightarrow ZZ/WW$ channels, whereas the effect becomes minor for $gg \rightarrow H \rightarrow \gamma\gamma$ channel because of destructive contribution of the fourth family charged lepton into $H \rightarrow \gamma\gamma$. However, situation could be changed if Higgs boson decays into fourth family fermions are allowed, e.g. for relatively light Higgs boson $\sigma(gg \rightarrow H) \times BR(H \rightarrow ZZ/WW)$ in SM4 may even be lower than in SM3 for certain values of the ν_4 masses (see Tables I and II in [5]).

A review of the recent experimental results on the Higgs boson searches is presented in [12, 13]. In several decay channels, the difference between the expectation and the observation reaches $+2\sigma$, as reported by both LHC experiments. Two most important differences are discussed below, as the remaining ones can

be eliminated as statistical fluctuation by comparing to the results from the other channels. The discrepancies are in $H \rightarrow WW \rightarrow \ell\nu\ell\nu$ channel in the region $120 < m_H < 180$ GeV observed by both ATLAS and CMS and in $H \rightarrow ZZ \rightarrow 2\ell 2q$ channel in the vicinity of $m_H \approx 500$ GeV as reported by CMS. The first excess surpasses 2σ between 135 and 150 GeV as reported by ATLAS and CMS result combination and CDF/D0 combination shows a similar deviation in $H \rightarrow WW \rightarrow \ell\nu\ell\nu$, as well. If the second excess is caused by the H boson, then the required cross-section becomes four times larger than the SM3 prediction [13]. This is exactly the factor predicted by SM4 (see Table II in [5]). In addition, ATLAS observed 2 events around 500 GeV in the “golden mode”. Justification of this observation would again require a factor of four to the production cross section. In the SM4 case, other channels studied by ATLAS and CMS exclude m_H around 500 GeV at less than 2σ .

In this study, it is shown that the opening of the $H \rightarrow \nu_4\bar{\nu}_4$ channel could essentially modify situation in 135 – 150 GeV region mentioned above, whereas its effect is negligible at 500 GeV since, WW and ZZ modes are dominant for $m_H > 170$ GeV independent of ν_4 mass. Nevertheless, if ν_4 is unstable (i.e. it decays within the detector) it could provide additional, so-called “silver” [14, 15], channel for Higgs discovery.

It is important to realise how the masses of the fourth generation fermions affect Higgs properties. The dependence of the cross section of the Higgs boson production via gluon fusion, on the masses of the fourth generation quarks is illustrated in Figures 1 to 5 of [11]. It can be seen that, the infinite mass limit of the fourth generation quarks gives the most conservative enhancement to the production cross section. This conservative enhance-

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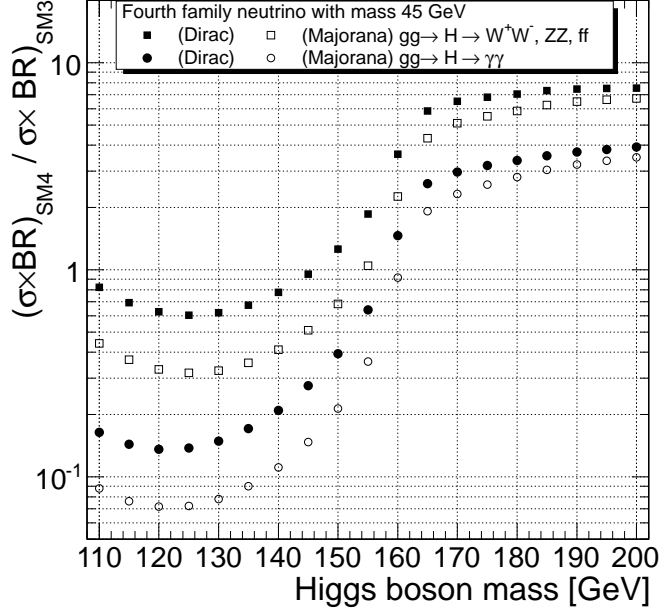


Figure 1: Ratio of $\sigma(gg \rightarrow H) \times BR(H \rightarrow X)$ predicted in SM4 to that in SM3 depending on the Higgs mass for $m_{\nu_4} = 45$ GeV.

ment has widely been used in most of the related studies to stay on the pessimistic safe side. However, making assumptions about the masses of the SM4 fermions might not be the best approach when the decay properties of the Higgs boson is under study.

The changes in the bosonic decay widths of the Higgs boson, e.g. $H \rightarrow gg, \gamma\gamma, Z\gamma$, due to SM4 are almost independent of the SM4 fermion masses. However, this is not the case for the decays of the Higgs boson into SM4 fermions, especially the SM4 neutrino.

The decay width of $H \rightarrow \nu_4 \bar{\nu}_4$ becomes very dominant over the other decay widths of Higgs boson, especially at relatively light SM4 neutrino mass. This property was demonstrated earlier in [5] and also in recent papers [16, 17]. The impact of such an SM4 neutrino can be observed in the change of the production cross section and the branching ratio of the Higgs boson in the following decay modes: $H \rightarrow WW, ZZ, ff$ and $H \rightarrow \gamma\gamma$. Here f denotes a charged fermion. The ratio of the $\sigma(gg \rightarrow H) \times BR(H \rightarrow X)$ in SM4 to SM3 case is the best parameter to demonstrate this effect. In the remainder of this study, the masses of the charged SM4 fermions are assumed to be heavy and m_{ν_4} is scanned from 45 GeV to 100 GeV both for Dirac and Majorana cases as shown in Figures 1 to 8. Numerical calculations are performed using COMPHEP [20, 21], HIGLU [22] and HDECAY [23] with appropriate modifications.

Experimental lower bounds on the SM4 neutrino mass are [18]: 45.0 GeV (90.3 GeV) for stable (unstable) Dirac and 39.5 GeV (80.5 GeV) for stable (unstable) Majorana

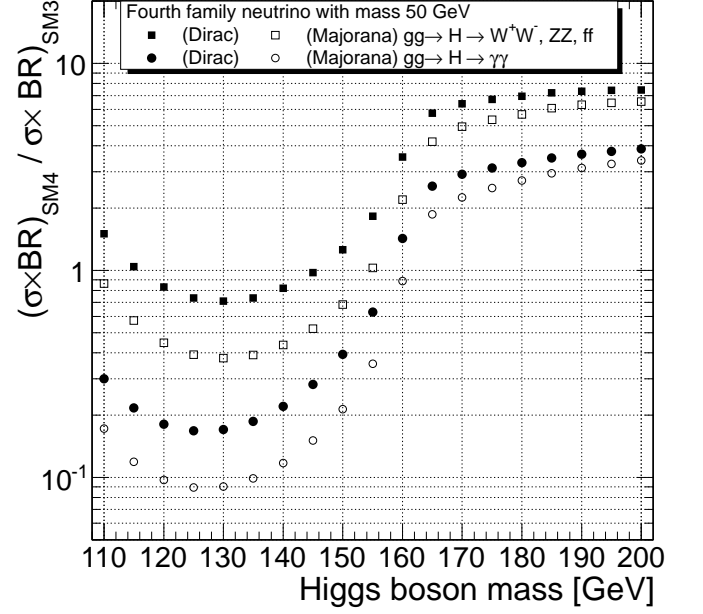


Figure 2: Same as Fig. 1 but for $m_{\nu_4} = 50$ GeV.

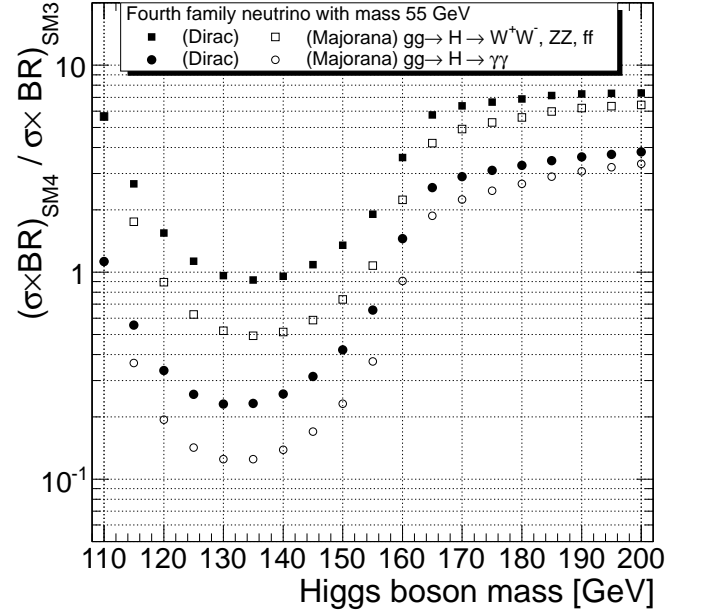


Figure 3: Same as Fig. 1 but for $m_{\nu_4} = 55$ GeV.

neutrino Majorana cases. In this context, stable means escaping the LEP detectors. For the unstable Majorana neutrino mass, a lower limit of 62.1 GeV has been recently suggested [19].

The change in the branching ratio of $H \rightarrow WW, ZZ, ff$ channels is purely due to the change in the

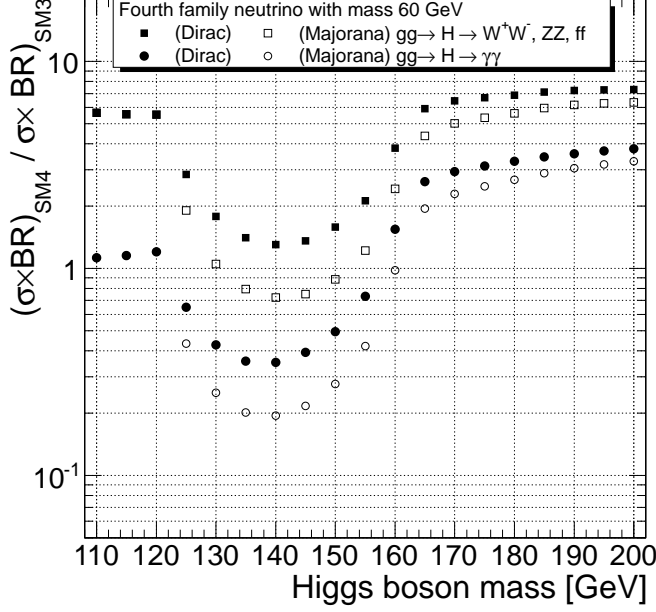


Figure 4: Same as Fig. 1 but for $m_{\nu_4} = 60$ GeV.

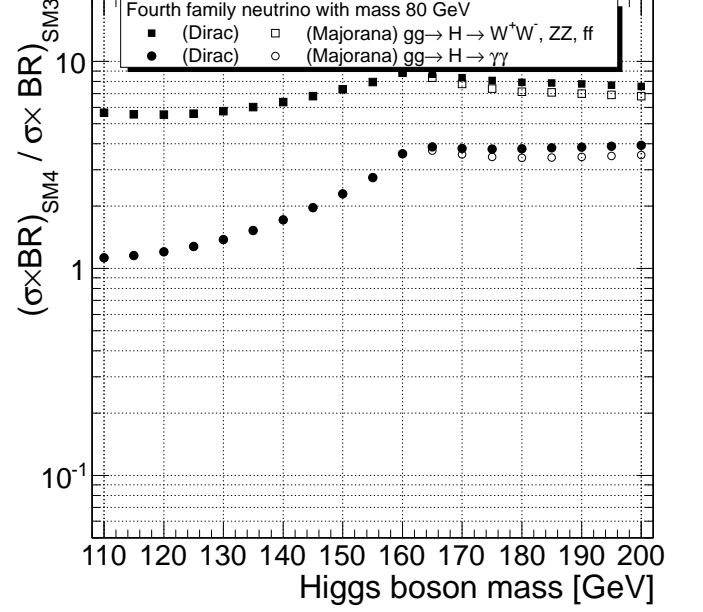


Figure 6: Same as Fig. 1 but for $m_{\nu_4} = 80$ GeV.

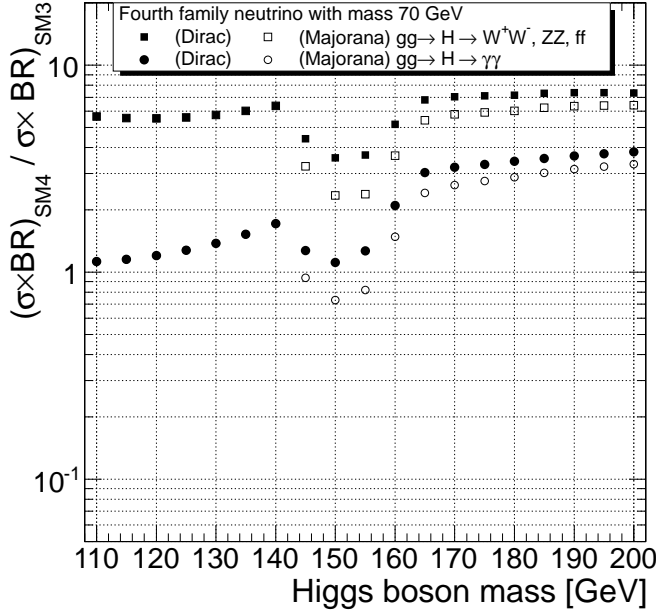


Figure 5: Same as Fig. 1 but for $m_{\nu_4} = 70$ GeV.

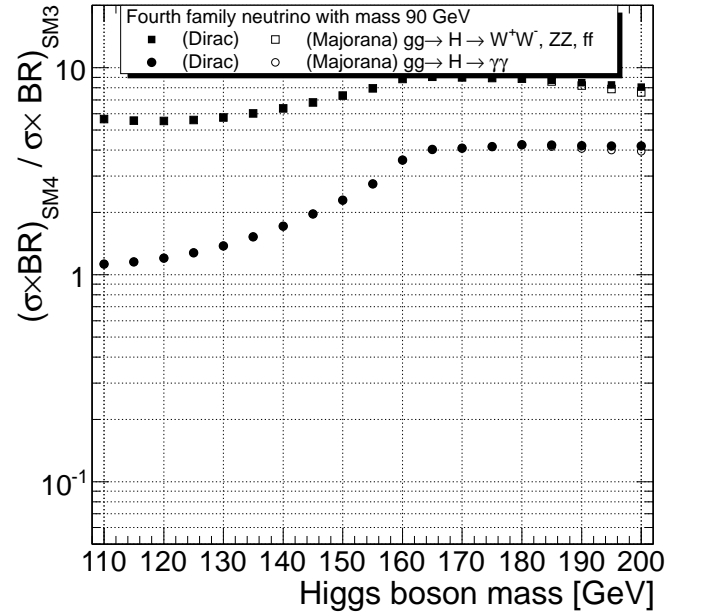


Figure 7: Same as Fig. 1 but for $m_{\nu_4} = 90$ GeV.

total decay width of Higgs boson. In the case of $H \rightarrow \gamma\gamma$ the destructive contribution of the charged SM4 lepton to the $H \rightarrow \gamma\gamma$ decay width results in a further decrease in its branching ratio.

Figures 1 through 8 show that SM4 case with neutrinos of masses up to 70 GeV hides the Higgs boson with re-

spect to SM3 expectations. Hence, any limit put on the Higgs boson mass especially for $m_H < 160$ GeV would need to be reconsidered in SM4 case. In other words “non observation” of a Higgs in this region would be interpreted as the non existence of the Higgs in SM3 case, whereas this would not be true in SM4 case.

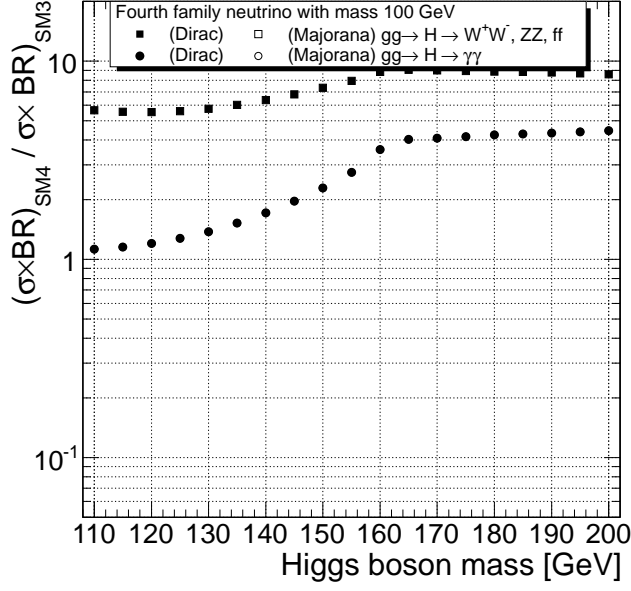


Figure 8: Same as Fig. 1 but for $m_{\nu_4} = 100$ GeV.

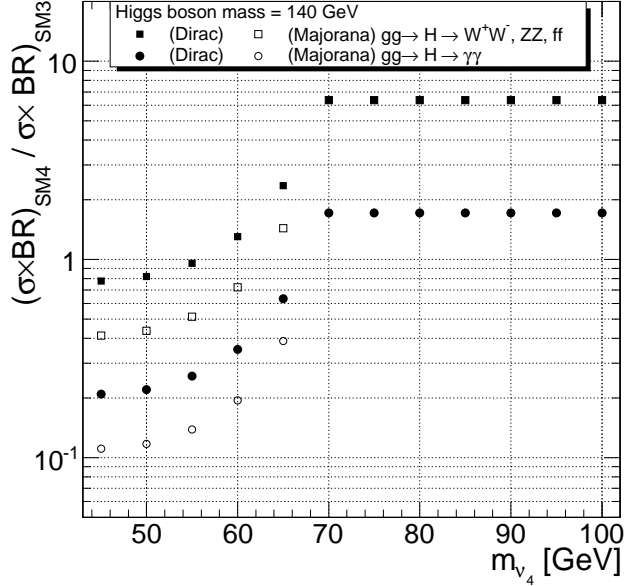


Figure 9: Ratio of $\sigma(gg \rightarrow H) \times BR(H \rightarrow X)$ predicted in SM4 to that in SM3 depending on ν_4 mass for $m_H = 140$ GeV.

It is seen that this ratio could essentially be below 1 (in the case of $H \rightarrow WW, ZZ, ff$) if m_{ν_4} is less than 55 (65) GeV in Dirac (Majorana) case. As a practical example to visualize the influence of ν_4 mass on the observable final states, a 140 GeV Higgs boson and heavy SM4 fermions with lighter neutrino are considered in Figure 9. It is

possible to use this Figure in conjunction with the current experimental results (i.e. Fig. 4 from [12, 13]) to make predictions on the type and mass of SM4 neutrino. If the observed deviation around 140 GeV is attributed to an SM-like Higgs, then according to the bottom part of Fig. 4 in [12, 13] best fit signal strength is $\sigma/\sigma_{SM3} \approx 0.5$ which corresponds to a Majorana neutrino with mass $m_{\nu_4} = 55$ GeV in Figure 9. Therefore, if studies with higher luminosity reveal that the deviation is not a statistical fluctuation but originates from a real Higgs boson, an SM4 with a "stable" neutrino would yield a possible explanation for this unexpected result, in addition to revealing the neutrino mass in an indirect way.

In conclusion, possible existence of the relatively light fourth family neutrino requires re-interpretation of the ATLAS and CMS results in the SM4 case. Namely, exclusion region for Higgs boson mass is reduced from 120–600 GeV to 160–500 GeV.

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